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BIM-enabled Modular and Industrialized Construction in China

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Abstract

Old-fashioned construction methods in China lead to many issues such as low field productivity, unreliable quality, high resource and energy consumption, frequent safety accidents, and significant environmental pollution. The concept of industrialization of construction has been recognized since the 1950's, but was not well developed until recently when the industry came under the pressure of increasing labour costs and the demand for sustainable development. There was a surge of Building Information Modeling (BIM) application in the last few years in China, and the industry has seen the many benefits of virtual design and construction. Integrating BIM technology into the industrialization of construction is seen as a promising opportunity to improve the performance of modular and industrialized construction. This paper first reviews the history of the industrialization of the Chinese construction industry, and then discusses the recent BIM adoption in China. The main focus of this paper is using BIM to support modular design and industrialized construction and installation in China. The use of some advanced hardware tools is also discussed, including the use of 3D laser scanners to collect as-built data and establish a point cloud model for better MEP system coordination, and the use of a robotic total station for fast installation.

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1. Introduction

China's swift economic development over the last thirty years created a huge construction market; however, the Chinese construction industry is still characterized by low field productivity, unreliable quality, high resource and

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energy consumption, frequent safety accidents, and significant environment pollution. These problems are all related to the labor-intensive nature of the Chinese construction industry as many projects employ a cast-in-place construction approach [1]. There is a demand for an advanced construction approach to increase the overall performance of the industry.

After the first round of industrialization stagnated in the late 1980's, industrialization of construction in China has been receiving more and more attention. The industrialization of construction was first initiated in the early 1950's during the first Five-Year Plan in order to meet the demand of facility reconstruction after World War II and the Civil War [2]. The first round of industrialization focuses on the standardization of design, mass prefabrication of construction components, and mechanization of on-site construction. Mechanized and automated construction methods contributed greatly to urban development in the next two decades. The concept of industrialization faded away in the 1980's along with Chinese economic reform. Fast economic development raised sharply both the level of people's income and expectations of housing quality. Due to the over-emphasis of standardization, only a few housing styles were previously available. Limited technology and construction materials at that point resulted in poor quality of prefabricated components. Thus the housing quality was low with issues of leaking and cracking. All of these did not satisfy the demand of a quickly expanding housing market. As a result, customized design and cast-in-place construction methods have been dominating the construction market since the 1990's [3].

The concept of industrialization was picked up again by the industry in the last few years for two main reasons. The first reason is a labour shortage and an increased labour cost. Along with the economic development, many new positions are available in the service industry such as banks and restaurants.These positions attract more young people because of the poor working conditions and safety concerns in the construction industry. At the same time, the average salary of construction laborers increased 31% from 2000 to 2009, which is far more than the rate of construction material prices and average salaries of all other industries [4]. As a result, the Chinese construction industry is facing an aging labour structure, and, in turn, the industry seeks industrialization to minimize the need for field labour. The second reason for renewed interest in industrialization is the demand for sustainable buildings and sustainable construction processes. Traditional construction processes consume more energy and produce more dust than modular construction, which assembles prefabricated components on site. Also, some new environment-friendly materials are more easily applied to prefabricated panels which meet the need for energy saving in the operation stage.

Application of Building Information Modeling (BIM) in the Chinese construction industry has surged since the Ministry of Housing and Urban Rural Development (MHURD) started to plan a series of national-level BIM standards [5]. With the help of an information-rich building models and data integration between business processes, BIM provides the industry with great potential to promote the industrialization of construction and improve the performance of modular construction. This paper first investigates the history of industrialization in the Chinese construction industry in terms of its origin, its potential, and the barriers to be overcome. Next, the adoption of BIM in China is studied in order to give an overview of BIM implementation in the world's largest construction market. The majority of this paper discusses the approach of BIM-enabled modular and industrialized construction and installation.

2. Modular and industrialized construction in china

The industrialization of construction has gone through three stages as shown in Table 1. The initialization stage ran from 1949, when the People's Republic of China was founded, to 1978, the first year of the Chinese economic reform. In order to meet the demand for housing after the Civil War, industrialization from the Soviet Union was introduced to China. This stage emphasized the standardization of housing design, especially of the precast concrete (PC) structural system. The early practices focused on PC slabs used on masonry structures, and later PC wall panels were used on high-rise apartment buildings. Along with the economic growth during the Chinese economic reform, demand for both housing quality and quantity increased. Therefore, the exploration stage focused on new supporting systems like SAR by John Habraken [6], new materials, the development of a modular coordination standard, and modular kitchen and bathroom facilities. At the same time, the concept of the housing industry (i.e., house planning, design, construction, renovation and decoration, maintenance, and operation management) was introduced to the Chinese economic system. The last stage emphasizes sustainable aspects of construction projects, such as

environmental protection as well as energy, water, land, and material conservation. Broad Homes, the leading company in this field, first developed an integrated and modular bathroom with Suzuki and then proposed a clustering system for building structures, doors, windows, kitchens, bathrooms, floors, HVAC, plumbing, and electricity. Wanke is the first and leading developer in China to produce industrialized apartment buildings. Its focus is manufactured building structure by PC components.

Every year, there are more than 2 billion square meters of new construction in China, which account for more than 50% of the total new construction in the world. However, the industrialization of construction in China isn't well recognized by the market; less than 1% of new construction is built in an industrialized approach. There are several barriers. Firstly, financial support from the Chinese government is lacking. The government encourages the industrialization of construction only at police talks. No actual capital investment or tax-saving for companies developing industrialized facilities or components is offered. Secondly, some building codes lag behind the technology of industrialization and, in many cases, industrialized building projects need special review and approval because some construction methods are beyond the regulation in current building codes. Thirdly, the administration of the construction industry is not ready for the industrialization process in many aspects, such as component manufacturing, bidding and tendering, and construction safety regulation. Finally, industrialized construction projects do not have attractive financial benefits. Every corporation is profit-driven. Sometimes, the cost of an industrialized building is higher than buildings delivered in a traditional method. For example, manufactured PC wall panels are more expensive than brick-mortar walls. Without proper intervention from the government and practical economic benefit achieved by a matured business chain for cost-effective industrialization, it is not easy to convince companies to practice modular and industrialized construction.

Fortunately, the Chinese government views industrialization as the trend of the construction industry to meet the demand for sustainable development. The construction market will be continuously increasing in the next two or three decades, and the new housing area in next thirty years will be 20-30 billion square meters. The goal set by the Ministry of Housing and Urban Rural Development (MHURD) is that over 50% of all housing projects (and over 60% affordable housing projects) should be built by industrialized construction by 2020 [5].

Table 1. The history of China's industrialization of construction

Stages	Driven Forces	Focuses
Initialization (1949-1978)	Demand on massive construction of housing and industrial facilities	Construction productivity
Exploration (1978-1998)	Demand on housing quantity and quality	Labour productivity, housing quality, construction speed
Transition (1998-now)	Multiple factors	Labour productivity and safety, building quality, construction cost, sustainability

3. BIM adoption in china

The Chinese construction industry got to know the concept of Building Information Modeling (BIM) around 2002. Only a few projects employed BIM until a few years ago when the benefits of BIM were commonly acknowledged by the majority of the industry. BIM application surged since 2012 when the MHURD started to plan a series of national-level BIM standards. Although many projects have started to use the BIM approach and most built environment professionals had knowledge of BIM, use of BIM in China remains relatively immature. Application of BIM occurred mostly in the design phase, especially in the early years of using BIM in China. The BIM use for cost and project management has received more attention in the last few years and has now become a main focus of project owners [7].

The most mature application of BIM in China is clash detection and integration/optimization of building service systems. The most common way in which industry professionals collaborate with each other in a BIM project is through building information models to analyze constructability issues and assess changes in terms of their impacts on cost and schedule [8]. A federated model is used to load several BIM models created by different parties into one

software platform for coordination. Autodesk Navisworks is currently the market leader in China as a platform for federated model review. Glodon model checker GMC2013 is a similar software application made by Chinese BIM software vendor Glodon.

4D-BIM is a great way to improve construction efficiency by optimizing a construction schedule [9]. There are two types of 4D-BIM applications in China. Most contractors just use 4D simulation to visualize a construction schedule planned in the traditional way. This level of 4D-BIM application can help in communicating schedules with involved parties but does not benefit a contractor much in terms of construction efficiency. Some contractors use 4D-BIM to analyze construction schedules by comparing different schedule options in terms of site logistics and time-space coordination. Few contractors have started to use advanced 4D/5D-BIM software tools, such as the flowline feature in VICO Office, to optimize construction schedules by reducing buffer time and lead time of construction activities.

The lack of BIM execution guidelines and BIM specialists are two significant challenges in China [1]. Due to the recognition of BIM benefits, many construction projects have a sudden demand for BIM, but the industry has no time to systematically study and research a strategic and technical execution approach suitable for local projects. Many projects take peer projects or foreign BIM Execution Plans as references. At the same time, due to the large scale of the Chinese construction market, BIM-capable professionals are lacking. In addition to managerial challenges, the lack of local BIM software tools is a technical challenge. Foreign BIM tools are not designed based on Chinese building codes and do not follow local industry conventions. This makes the model rarely to be directly used for some technical analyses which involve local rules.

With the contentious efforts by the government and the industry, the Chinese construction industry will definitely see quick growth in using BIM technology to improve its overall performance. Along with the increasing attention on modular and industrialized construction, integrating BIM technology into the industrialization of construction is seen as a promising opportunity to expand this market. The next section will discuss a way of using BIM to support modular and industrialized construction.

4. BIM-enabled modular design

BIM-enabled modular design is based on the modularization of building components. The modular design has been applied to high-rise apartment buildings by Wanke, the largest housing developer in China. This design method is more suitable for buildings with similar layouts or unit assemblies such as affordable housing developments. Due to the constraints on the total area of a housing unit and the cost of each unit area, there are not many choices for the layout of affordable housing. The only variability is the number of units on a standard floor and the layout of a housing unit (with limited customization on dimensions). BIM is used in order to support the parametric design at different module levels. The first level of modularization is the unit layout. The unit module is then disassembled into room-level modules such as the bathroom module or kitchen module. The next level of module includes building components like wall panels or the plumbing system, as shown in Figure 1 [10].

The design process starts by selecting a number of desired units based on their layouts from the Unit Layout Library (ULL) and then assembling a floor plan by customizing dimensions. After the architectural design is proposed, a structural engineer will create a structural model by selecting appropriate modules from the Structural Module Library (SML) and then send the structural model to the mechanical software for analysis. At the same time, an MEP designer also takes the advantage of a library of MEP modules, which are assemblies of a set of MEP components that facilitate the design of building service systems.

5. BIM-enabled industrialized construction & installation

The first application of BIM in the industrialization of construction is clash detection and constructability analysis during the pre-construction stage. There are several hundred or thousand prefabricated components in a PC building, as such, by traditional approach of constriction drawing review and coordination meetings, it is hard to make sure that there is no conflict during on-site construction. Some conflicts, especially clashes caused by reinforcement bars or embedded parts in PC components, are more difficult to deal with than cast-in-place construction. By developing digital models for each component and putting all models together in a virtual construction process, Shanghai Urban

Construction Group (SUCG), the leading PC building construction company in China, has resolved many simple but repeated constructability issues that happen on site during the fabrication process.

A more attractive benefit to PC component manufacturers is that the BIM models of PC components provide the manufacturer with valuable data to support the integration of design, manufacturing, construction, and even the operation/maintenance processes. The data in a BIM model can also support the whole manufacturing process, including material ordering, in-factory logistics, packaging, stocking, and transportation to the construction site. SUCG established a BIM-data platform to support four systems: a component design and detailing system, a manufacturing management system, an on-site construction management system, and a remote monitoring system [11]. This platform largely improved project performance in quality, schedule, and cost.

Fig. 1. Modules at different level and the on-site erection of components

Fig. 2. Point cloud model combined with robotic total station layout

Some large MEP contractors have begun to practice the concept of industrialized installation. BIM models provide the MEP contractor with accurate geometric information of the service systems of a construction project. System integration and coordination supported by model checkers such as Autodesk Navisworks and Solibri will solve the old problem of system layout and sizes not being accurate. Although the design information of the MEP system is very accurate in BIM models, the physical installation conditions are normally not as ideal as the computer's model due to the varying quality of concrete structures. This is the issue faced by early practitioners who fabricated system components such as ducts and pipes in factories. Recently some sophisticated MEP contractors started to employ 3D laser scanning equipment to create an as-built point cloud model of the structure system. They

then used it to calibrate the design model of the MEP system to produce accurate fabrication drawings. This is the approach used by the Pingan Tower project in Shenzhen, China. The MEP contractor also used a robotic total station combined with BIM models to ensure fast and accurate layout of MEP systems, as shown in Figure 2 [12].

6. Conclusion

Rapid economic development in China requires a healthy and sustainable construction industry to meet the demand for civil facilities and infrastructure. After decades of limited development in industrialization of construction, the widespread adoption of BIM has been seen as a way to accelerate growth of modular and industrialized construction in both the technical and management fields. Recent practices in China have demonstrated that innovations in BIM-enabled modular design, clash detection, and constructability study by BIM models facilitate the fabrication process, manufacturing management by data retrieved from BIM models, and the use of 3D laser scanning technology to ensure accurate geometric information of MEP systems. The implementation of BIM in the Chinese construction industry in the near future, will unearth more benefits of modular and industrialized construction, such as material conservation, higher construction quality, shorter construction time, and a safer working environment.

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